NATIONAL BUREAU OF STANDARDS REPORT
3203

CAPACITY TESTS OF TWO REFRIGERATION COMPRESSORS
THERMO-KING, MODEL 4R AND UNIVERSAL, MODEL VFP

by

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Report to

Headquarters, U. S. Marine Corps
Department of the Navy

NBS

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NATIONAL BUREAU OF STANDARDS

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G-14153

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NBS PROJECT | **NBS REPORT**

1000-30-4830 April 2, 1954 3203

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Abstract

Determinations were made of the net refrigerating capacity of a Marine Corps standard Thermo-King refrigerating unit for a 600 cu. ft. warehouse at refrigerator temperatures of 0°F and 35°F and with an ambient temperature of 110°F. Subsequently the capacity of the compressor was measured with a secondary refrigerant calorimeter for each of the two operating conditions. The capacity of a Universal, Model VFP, compressor was measured with the calorimeter for a range of speed from 1600 rpm to 3000 rpm to determine whether or not it could be substituted for the Thermo-King compressor in the standard warehouse refrigerating unit. It was found that the Universal compressor produced a capacity equal to that of the Thermo-King compressor at approximately equal theoretical displacement, but the required rotative speed for the Universal compressor was in the range from 2700 rpm to 3000 rpm because of its smaller bore and stroke. Two specimens of the Universal compressor failed mechanically during the tests; a connecting rod broke on one specimen and the eccentric assembly separated from the crankshaft in the other specimen. Because of these failures it was concluded that the Universal compressor could not be expected to function satisfactorily in the standard Thermo-King warehouse unit.

1. INTRODUCTION

At the request of the U. S. Marine Corps, as outlined by letter dated September 18, 1953, capacity tests were made of a Marine Corps standard Thermo-King refrigerating unit for a 600 cu. ft. refrigerated warehouse and calorimetric measurements were made of both the original compressor in this unit and a proposed alternate compressor furnished by

the Engineer Supply Section, Supply Branch, Headquarters U. S. Marine Corps.

A primary purpose of the tests was to determine if the proposed alternate compressor could be used satisfactorily in place of the original compressor in the Marine Corps standard refrigerating unit. The compressor originally installed in the unit was a Thermo-King Model 4R, manufactured by the U. S. Thermo Control Company of Minneapolis, Minnesota. The alternate compressor, a Universal Model VFP, was manufactured by Tecumseh Products Company of Tecumseh, Michigan.

Tests were made to obtain the following information:

1. Refrigerating capacity of the refrigerating unit in an ambient temperature of 110°F with refrigerator temperatures of 0°F and 35°F, respectively.

2. Capacity of the Thermo-King compressor alone as measured by calorimeter for conditions of suction pressure, discharge pressure, suction gas temperature, and speed identical to those observed during the tests of the entire unit.

3. Capacity of the Universal Compressor as measured by calorimeter, at various speeds ranging from 1600 rpm to 3000 rpm with other conditions the same as for the Thermo-King compressor.

4. Comparison of the general construction and performance of the two compressors in order to evaluate their relative merits for application to the Marine Corps standard refrigerating unit.

2. TEST SPECIMEN

The specimen refrigerating unit, Thermo-King Model MQ 51 was of the plug-type, of nominal one-ton capacity equipped with a gasoline engine drive which was designed to refrigerate a 600 cu. ft. sectional walk-in box in the field where a source of electric power was not available for refrigeration purposes. The 600 cu. ft. box used for these tests was manufactured by Hussman Refrigeration, Inc. of St. Louis, Missouri. The unit was powered by a straight four-cylinder four-cycle engine manufactured by Crosley Motors of Cincinnati, Ohio. Components of the refrigeration circuit, such as compressor, condenser, evaporator and blowers were manufactured by the U. S. Thermo Control

Company. The compressor, Model 4R, had four cylinders with bore and stroke of 2-1/4 in. and 1-3/8 in. respectively. The compressor was coupled directly to the engine and the evaporator and condenser fans were driven by two double-V belts. The refrigerant used was dichlorodifluoromethane.

The Universal compressor, Model VFP, manufactured by the Tecumseh Products Company failed mechanically during the test and another compressor was submitted by the manufacturer's representative. The two compressors were practically identical except that the design of the crankcase and the crank shaft seal varied slightly. Each compressor had four cylinders with bore and stroke of 1-3/4 inch.

3. TEST PROCEDURE

The Thermo-King Model MQ51 plug-type gasoline-engine-driven warehouse-refrigerating unit was designed for a nominal capacity of one ton (12,000 Btu/hr) under conditions of 0°F warehouse temperature and 110°F ambient temperature.

Since there are losses in a refrigerating system the compressor must produce a capacity greater than the net capacity available in the refrigerated space. For this reason it was necessary to: (1) measure the net refrigerating capacity of the assembled unit under specified conditions (2) observe the exact conditions existing at the original compressor during such test (3) remove the original compressor from the unit and measure its refrigerating capacity under these identical conditions--before the next step (4) which was to determine the speed required for the alternate compressor to deliver the same or more capacity than the original, all other conditions being the same.

The Model MQ 51 Thermo-King refrigerating unit with Thermo-King compressor, Model 4R, was mounted in the 600 cu. ft. test warehouse. The entire system was operated in a room where the ambient temperature was controlled at the desired level. By adjusting an internal heat load the warehouse temperature was also maintained at the desired level.

Prior to the capacity tests, a reverse heat-flow test was made to determine the rate of heat transfer through the warehouse wall, which constitutes part of the refrigerating load. The refrigerating unit was in place but was not operated during this test. The ambient temperature was held at 30°F and the warehouse temperature was maintained at 130°F while observations of temperatures and the amount of heat required to maintain this temperature difference were made at 30 minute intervals for six hours after a steady state condition was reached.

For the two capacity tests the refrigerating unit was operated in an ambient temperature of 110°F while the warehouse temperatures were maintained at 0°F and 35°F, respectively. In addition to the above observations, pressures, speeds and gasoline consumption were measured.

Compressor capacities were determined by use of a secondary refrigerant calorimeter in accord with the method outlined in the A.S.R.E. Standard No. 23-R, Methods of Rating and Testing Refrigerant Compressors. The liquid refrigerant quantity method, as described in the A.S.R.E. Standards No. 23-R, was employed to check the capacity determined by the primary test method. The conditions of the refrigerant (pressure and temperature) entering and leaving the compressor during tests of the entire unit in the warehouse were duplicated for these calorimeter tests of the compressors alone. These conditions were: suction gas temperature of 81°F and suction and discharge pressures of 0.6 psig and 177 psig respectively for the first series of tests, corresponding to a refrigerator temperature of 0°F; and 13.1 psig and 211 psig respectively, with the same suction gas temperature for the second series of tests, corresponding to a refrigerator temperature of 35°F.

For the first series of test, the speed of the Universal compressor was varied from 1750 rpm to 3000 rpm in approximately 250 rpm increments for successive tests. For the latter series of tests the compressor speed was varied from 1600 rpm to 2350 rpm in increments of approximately 250 rpm for successive tests. Tests at more than one speed were made only on the Universal compressor(s) during both series and the second series was terminated at 2350 rpm because of the mechanical failure of the second Universal compressor. The first Universal compressor failed mechanically during the second test in the first series.

The Thermo-King compressor was tested once for each series of tests, at 2300 rpm and 2100 rpm respectively, which were the original speeds of the compressor as installed in the unit during the unit capacity tests. Capacity tests of the Thermo-King compressor at various speeds were not requested. One additional test of the Thermo-King compressor was made at an A.S.R.E. Standard Rating condition for reference purposes. The standard rating selected called for conditions of: suction pressure 4.5 psig; discharge pressure 117 psig; and suction gas temperature 65°F.

For all compressor calorimeter tests, an oil separator was used in the discharge line to keep the oil out of the calorimeter and thus simplify capacity measurements. However, the oil was returned to the suction line to simulate normal oil return in

the Thermo-King refrigeration unit. A shunt-wound 5 H.P. direct-current variable-speed motor was used to drive the compressor in all but one of the calorimeter tests. After the calorimeter reached steady state conditions, the compressor under test was run for two hours, and observations of temperature, pressure, speed, voltage, current, power consumption and liquid refrigerant flow were made every twenty minutes.

Calibrated thermocouples, pressure gages, and other instruments were used for the various measurements.

4. TEST RESULTS

The heat transmission factor of the 600 cu. ft. warehouse used to test the unit was found to be 59.5 Btu/°F(HR).

The capacity tests showed that the Thermo-King MQ51 refrigerating unit had capacities of 10,100 Btu/hr at 0°F warehouse temperature and 23,900 Btu/hr at 35°F warehouse temperature with an ambient temperature of 110°F. in each case. The results are tabulated in Table 1.

Table 1 also shows the results of the Thermo-King compressor capacity tests determined by calorimeter measurements. The maximum deviation between the primary and secondary methods used in all calorimeter tests reported was 3.3% of the capacities indicated by the primary method as described under Test Procedure.

Table 2 shows the results of the capacity tests of the Universal compressor on the secondary refrigerant calorimeter.

The capacity versus speed of the two models of refrigeration compressors is plotted in Fig. 1 for the two series of tests.

The lower curve shows the observed capacities for the Universal Model VFP compressor for various speeds and at the conditions established for a 0°F warehouse and 110°F ambient temperature.

The upper curve shows the observed capacities for the same compressor for various speeds and at the conditions established for a 35°F warehouse and 110°F ambient temperature. The curve is extrapolated as a straight line from 2300 rpm to 3000 rpm.

The observed capacities of the Thermo-King Model MQ51 unit was 23,900 Btu/hr at 2084 compressor rpm for conditions of 35°F warehouse temperature and 110°F ambient temperature, and the capacity was 10,100 Btu/hr at 2291 compressor rpm for conditions of 0°F warehouse temperature and 110°F ambient temperature.

The Thermo-King Model 4R compressor, when tested on the calorimeter at the same suction and discharge conditions showed capacities of 13,700 Btu/hr at 2298 rpm for conditions corresponding to the lower warehouse temperature and 24,800 Btu/hr at 2096 rpm under conditions corresponding to the higher warehouse temperature. The characteristic of the governor on the Thermo-King MQ51 unit was such that an appreciable speed change was required to establish a different throttle position on the gasoline engine. This accounts for the difference of about 200 rpm in compressor speed between the tests at 0°F and 35°F warehouse temperature.

The capacity observed during a third test of this compressor was 27,900 Btu/hr at 2404 rpm under conditions of 4.3 psig suction pressure 117 psig discharge and 62.0°F suction gas temperature. These conditions approximated one of the standard A.S.R.E. rating points. A test of the Universal compressor would have been made under these conditions and at a speed which would produce equivalent theoretical displacement if both of the Universal samples submitted had not failed mechanically.

During the tests of the Universal compressor(s) it was observed that the quantity of oil circulated through the system by the compressor increased noticeably as the oil level approached the maximum level allowed. Other conditions being equal this increase in oil circulation tended to increase the compressor temperature.

The Thermo-King Model 4R compressor was equipped with a built-in pressure-limiting device in the suction which modulated the flow of suction gas to the cylinders so that the pressure in the crankcase and cylinders was limited to approximately 19 psig, during the suction stroke for normal operation. In addition the modulating valve could be closed by means of a built-in solenoid valve blocking flow of all gas to the crankcase or cylinders to unload the compressor.

A test at 3000 rpm was attempted initially with the first Universal compressor submitted to match the theoretical displacement of the Thermo-King compressor. However, the speed was unstable so the first test was made at a speed of 1746 rpm (test 1, Table 2). This compressor failed mechanically during the course of the second test being made with it.

At the time of failure the compressor had been operated for 45 minutes at 1500 rpm and then 30 minutes at 1995 rpm during the second test when one of the connecting rods broke just below the wrist pin bearing.

Test 1 was repeated and a total of ten runs were made with the second Universal compressor submitted. The second compressor failed at 3000 rpm after running for three hours at that speed. In this case the eccentric assembly separated at the point where it was locked to the shaft. This caused damage to other parts. The damaged compressor parts are shown in Fig. 2.

No dynamometer tests were made of the compressors to determine the power required to drive them. Observations of the total power input to the motor used during the calorimeter tests were made, however. Considering the fact that various pulley and belt combinations were employed at various stages of the tests, and considering further that the motor losses are not known, these total power measurements are not suitable for determining the absolute power requirements but are definitely of value in establishing relative power requirements.

Fig. 3 shows the power consumed by the motor which operated the compressors under test. Three tests were made of the Thermo-King Model 4R compressor, one at conditions corresponding to 0°F warehouse temperature, one at conditions corresponding to 35°F warehouse temperature and one at 4.3 psig suction pressure, 177 psig discharge pressure, 62°F suction gas temperature at a speed of 2404 rpm. Power consumed for the three tests was 4160, 5898 and 5739 watts respectively.

For the series of tests of the Universal compressor(s) at conditions corresponding to 0°F warehouse temperature, the power consumption ranged from 2746 watts (avg) at 1747 rpm (avg) to 4568 watts at 3029 rpm.

The series of tests of the Universal compressor at conditions corresponding to 35°F warehouse temperature was interrupted by mechanical failure of the test specimen. Observed power consumption for the tests run ranged from 3758 watts at 1625 rpm to 5614 watts at 2343 rpm. The extrapolation of this curve, as shown by the dotted line on Fig. 3 indicates an expected power input of 7010 watts at 2740 rpm (2740 rpm is the speed of the Universal necessary for equivalent displacement to the Thermo-King at 2096 rpm), and an expected power input of 6500 watts at 2595 rpm, at which speed the extrapolated capacity curve (see Fig. 1) indicates equivalent capacity to the Thermo-King compressor operating at 2096 rpm.

From these values, the refrigerating capacity per watt input to the driving motor was 3.3 Btu(hr)/watt for the Thermo-King compressor and 3.0 Btu(hr)/watt for the Universal compressor at conditions corresponding to 0°F warehouse temperature. For condition corresponding to 35°F warehouse temperature, the ratio was 4.2 Btu(hr)/watt for the Thermo-King compressor compound to 3.8 Btu(hr)/watt for the Universal compressor (extrapolated).

5. DISCUSSION AND CONCLUSION

Under identical conditions, except for speed, the capacity of the Universal compressor(s) had a linear relationship with speed, within the range of both series of tests, as shown in Fig. 1.

Since the capacity curve for the first series of tests shown in Fig. 1 was a straight line at least up to 3000 rpm, it was assumed to be reasonable that the same characteristic would hold true for the portion of the second series of tests that could not be made because of mechanical failure of the two Universal compressors submitted. Accordingly, the extrapolation for the upper curve in Fig. 1 was shown as a straight line.

Within the speed range from 1600 rpm to 3000 rpm it is probable that a similar linear relationship existed for the Thermo-King compressor as for the Universal compressor(s). Because of the difference in theoretical displacement the Thermo-King compressor had greater capacity for equal speeds than the Universal compressor. The displacement of the Thermo-King compressor was 21.9 cu. in./rev. and of the Universal was 16.8 cu.in./rev. Accordingly the speed at which the Universal would have to operate to have equivalent theoretical displacement to the Thermo-King operating at 2100, 2300 and 2400 rpm would be 2740, 3000, and 3130 rpm respectively.

The capacity of the Thermo-King compressor at 2300 rpm, when the suction pressure and discharge pressure was 0.4 psig and 177 psig, was equal to that of the Universal compressor at 3000 rpm as shown in Fig. 1. This was in agreement with the displacements of the two compressors. However, following the extrapolated portion of the curve for the other series of tests at a suction pressure of 13.1 psig and discharge pressure of 211 psig the capacity of the Thermo-King compressor at 2100 rpm was lower than that predicted for the Universal compressor at the speed of equal theoretical displacement, 2720 rpm.

This indicated inconsistency is not fully explained by the test data but it suggests the possibility that the extrapolated curve should not actually be a straight line.

Mechanical failure of two specimens of the Universal Model VFP compressor was observed, and in both cases at speeds below the minimum speed required to produce a capacity equal to that of the Thermo-King Model 4R compressor. These failures are the primary basis for the conclusion that the Universal Model VFP compressor cannot be expected to function satisfactorily in the Thermo-King Model MQ51 warehouse refrigerating unit.

From observations of the total power input to the motor (including belt and motor losses) used to drive the Thermo-King and Universal compressors in the calorimeter tests, it appeared that approximately 10 percent more power was required for the Universal compressor than for the Thermo-King compressor for equivalent capacity.

In view of the mechanical failures of the Universal compressors it was not considered essential to study other problems such as drives, mounts, compressor body cooling, fit, weight, etc., related to substitution of the Universal Model VFP for the original Thermo-King Model 4R compressor.

Test	N at
1	
2	

Test
1
2
3

TABLE 1

THERMO-KING MODEL MQ51, UNIT CAPACITY TEST

Test	Net Refrigerating Capacity Btu/hr	Compressor Speed rpm	Condenser Fan Speed rpm	Evaporator Fan Speed rpm	Warehouse Temp. °F	Ambient Temp. °F	Suction Pressure PSIG	Discharge Pressure PSIG	Suction Gas Temp. °F	Temp. of Liquid Entering Exp. Valve °F	Gasoline Consumption lb/hr
1	10,100	2291	1471	1234	-0.8	109.6	0.6	177	79.6	56.1	6.2
2	23,900	2084	1319	1094	34.3	109.7	13.0	211	82.8	83.4	6.7

THERMO-KING MODEL 4R, COMPRESSOR CAPACITY TEST

Test	Compressor Capacity Btu/hr	Compressor Speed rpm	Suction Pressure PSIG	Discharge Pressure PSIG	Suction Gas Temp. °F	Temp. of Liquid Entering Exp.Valve °F	Compressor Ambient Temp. °F
1	13,700	2299	0.4	177	81.2	111.4	91.5
2	24,800	2096	13.1	211	81.2	117.1	112.1
3	27,900	2404	4.3	117	62.0	84.8	89.0

Table 2

UNIVERSAL MODEL VFP, COMPRESSOR CAPACITY TEST

Test	Compressor Capacity Btu/hr	Compressor Speed rpm	Suction Pressure PSIG	Discharge Pressure PSIG	Suction Gas Temp. °F	Temp. of Liquid Entering Exp. Valve °F	Compressor Ambient Temp. °F
					First Series		
1	9200	1746	0.7	177	80.2	111.0	89.8
2	8800	1748	0.6	180	82.2	110.5	76.3
3	10,000	1998	0.5	179	82.9	114.0	86.5
4	11,400	2255	0.6	176	81.4	114.8	91.4
5	11,400	2525	0.6	178	80.9	114.6	88.5
6	12,700	2760	0.6	177	80.8	116.0	95.2
7	13,700	3029	0.6	177	81.2	115.8	91.9
					Second Series		
8	16,300	1625	13.1	211	81.3	129.7	92.2
9	17,900	1860	13.0	211	81.2	130.1	96.3
10	20,800	2122	13.1	211	80.8	131.4	102.3
11	22,400	2343	13.2	212	81.2	130.3	95.2

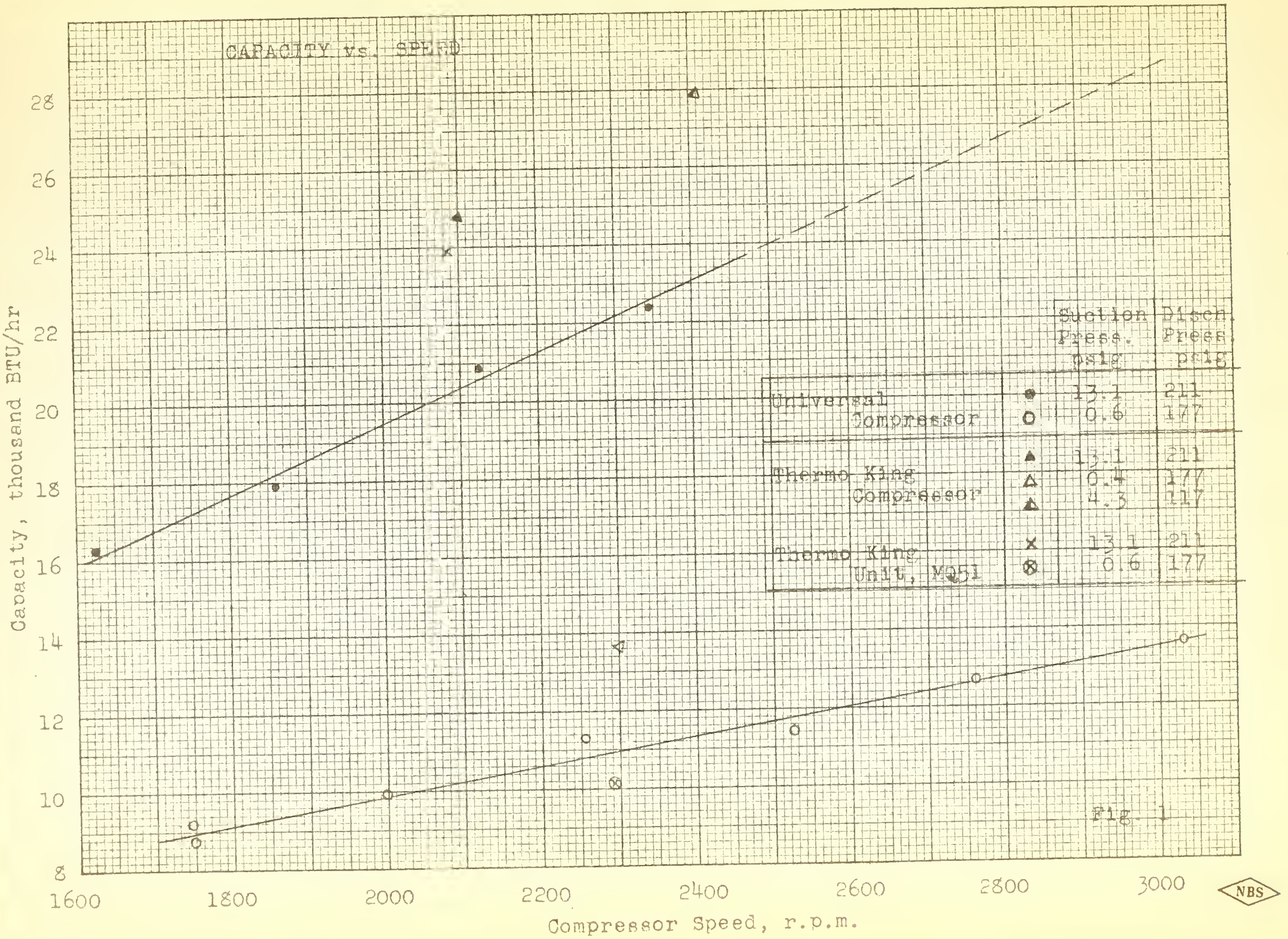
CAPACITY vs. SPEED
Suction Press. psig
Disch. Press. psig
Universal Compressor
13.1
211
0.6
177
Thermo King Compressor
13.1
211
0.4
177
4.3
117
Thermo King Unit, MQ51
13.1
211
0.6
177
Capacity, thousand BTU/hr
28
26
24
22
20
18
16
14
12
10
8
1600
1800
2000
2200
2400
2600
2800
3000
Compressor Speed, r.p.m.
Fig. 1

Fig. 2

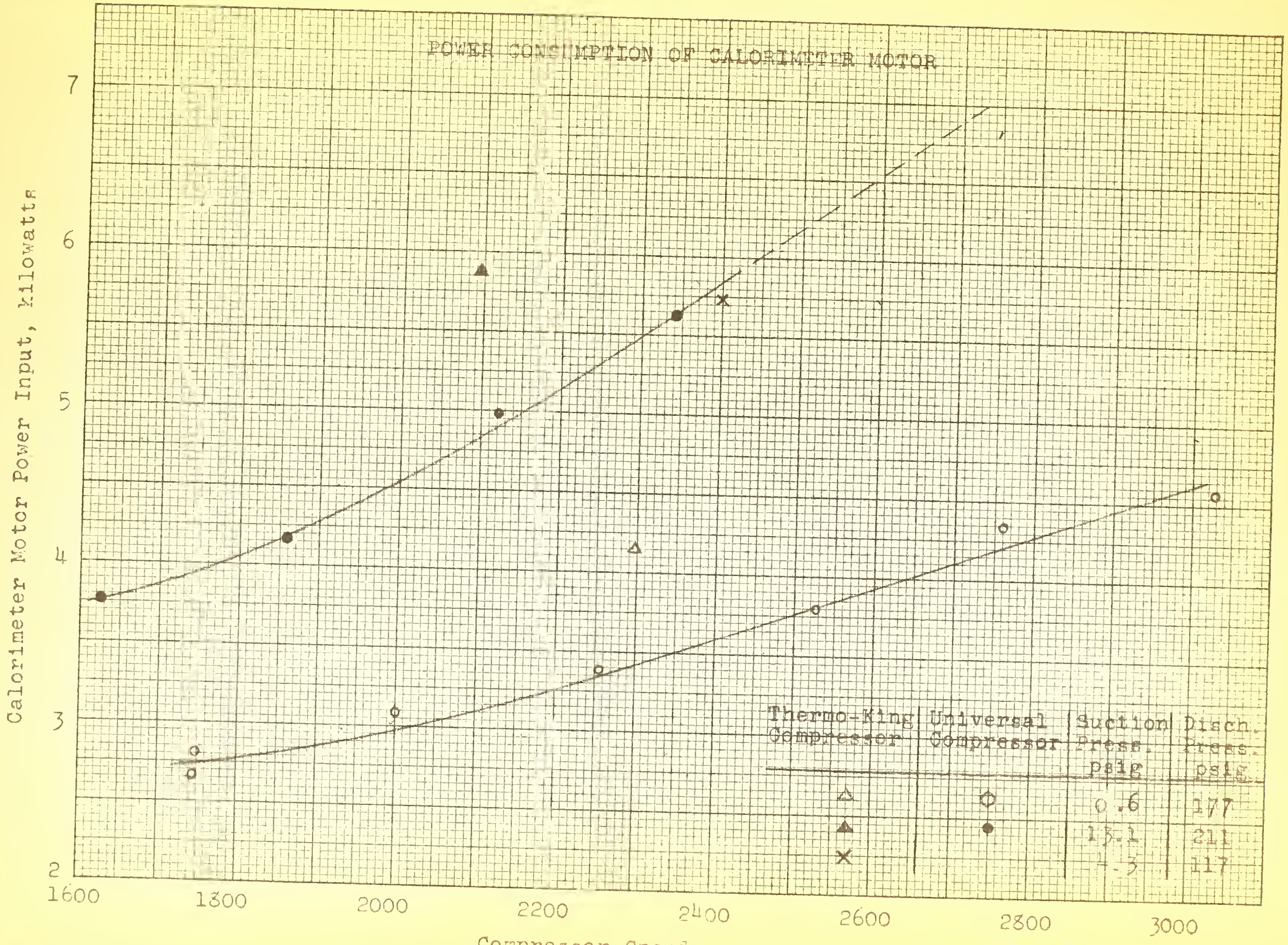
POWER CONSUMPTION OF CALORIMETER MOTOR
Calorimeter Motor Power Input, kilowatts
2
3
4
5
6
7
1600
1800
2000
2200
2400
2600
2800
3000
Compressor Speed, r.p.m.
Thermo-King Compressor
Universal Compressor
Suction Press. psig
Disch. Press. psig
0.6
177
13.1
211
-3
117

Fig. 3

THE NATIONAL BUREAU OF STANDARDS

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